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AES-2006 NPPs with VVER-1200 UNITs as a new approach to display of information from technical diagnosis systems

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Abstract

Operator performance in the main control room (MCR) depends to a great extent on the form and amount of the information on the nuclear plant process status. An unstructured form of data display may result in an increase in the data processing time and in errors in the decisions made by operators. Convenience of the NPP data flow handling is given an increased focus but the process of supplying diagnostic data to operating personnel is neglected by both the developers of technical diagnosis systems and by the MCR interface designers. The paper provides an analysis of the upper-level information from technical diagnosis systems and presents requirements to respective screen forms and implementation options.

Keywords: VVER-1200; Technical diagnosis system; Diagnostic information; Hierarchical structure; Reporting; Screen form; Information noise.

Introduction

Technical diagnosis systems (TDS) of modern NPPs has come a long way of evolution from primitive systems with a small number of measuring channels and limited data processing capabilities to complex software and hardware packages integrating functionally diverse TDS systems. Thus, for example, the monitoring, control and diagnosis system (MCDS) designed for Novovoronezh II AES-2006 nuclear power plant includes systems for:

- vibration monitoring (VMS);
- loose object detection (LODS);
- acoustic leak monitoring (ALMS);
- leak humidity monitoring system (LHMS);
- residual life automatic monitoring (RLAMS);
- multipurpose diagnosis (MDS);
- integrated analysis (IAS).

Besides the TDS systems integrated immediately in the MCDS systems, there are autonomous systems for specific applications. Primarily, these are an integrated valve diagnosis system (IVDS) and an automated vibration diagnosis system (AVDS). It is planned that AES-2006 NPP with the VVER-1200 reactor will include a total of nine diagnostic systems operating based on similar but different algorithms.

Traditionally, the process of providing the NPP's operating personnel with diagnostic information is neglected both by the TDS developers and by the main control room (MCR) interface designers. Essentially, the problem consists in that operation of present-day TDS systems requires special knowledge in digital processing of signals, vibration dynamics of rotor machines, reactor physics and other fields operating personnel do not have despite being highly qualified. Moreover, most conclusions on the status of equipment are probabilistic, while the personnel responsible for running the process need exact answers to exact questions. The TDS developers design interfaces of systems based on the knowledge and the experience of technical diagnosis experts, while operating personnel are accustomed to receiving information in an absolutely different form. It is from this that the misunderstanding between the technical diagnosis experts and operating personnel arises, which often leads to conflicts. The notion "operating personnel" includes not only

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the MCR personnel but also operating personnel of the reactor department, the turbine department, the electrical shop, and the thermal automatics and measurement shop, as well as the personnel of the departments involved in the NPP process running.

Stages in the NPP equipment with technical diagnosis systems

To make it clear for understanding what will be said below, we shall look in brief at the history of the NPP equipment with different TDS systems. The authors conditionally divide the entire path of the TDS technology introduction, assimilation and operation into four stages.

The initial TDS evolution stage is peculiar in that NPPs lacked not only dedicated systems for equipment diagnosis but sometimes even tools for collection of respective information, leave alone online display of processed data on the equipment status. The diagnosis process often relied on enthusiasm of individual personnel.

As far as specific features of this stage are concerned, the diagnostic process, as applied to the conditions of Novovoronezh NPP, looked as follows (only vibration measurements are considered). Vibroacoustic sensors were installed on the monitored equipment (often one sensor for a component). The received signal was amplified, filtered and sent to the device that processed the electrical signal into a sound. If desired, the operator could choose the required channel selectively and “listen” to the operation of each equipment unit. And the defect was detected “by ear”. It is clear that one should be very cautious when speaking about accuracy or reliability of defect detection. Later on, with the advent of early, still primitive instruments for multichannel recording of signals (magnetographs) with a capability for fast Fourier transform (the basis of spectral analysis), it became possible to record and process data in laboratory conditions. In this case, naturally, one could hardly speak about online data display in any form.

At the second stage, Siemens TDS systems were purchased for technical diagnosis applications and partially adapted for operation at Russian NPPs. The systems were introduced at units 1 and 2 of Kola NPP, and at units 3 and 4 of Novovoronezh NPP. Since each system was designed to detect only one diagnostic symptom (e.g. an increase in the acoustic noise in excess of the threshold value could signal of a potential leak), this class of systems started to be called local diagnosis system (LDS) [1–4]. Long-term operation of TDS systems with further upgrading of both hardware and software products has shown that these systems fully perform their functions. It should be noted that, despite an advance in the solution of technical diagnosis tasks, the problem of supplying operating personnel with information on the status of process components has never been solved. On the one hand, the TDS systems as such were fully closed systems, since they were originally intended not for transmission of data to external data systems, and, on the other hand, the very information structure of power units was very primitive and highly undeveloped. Therefore, the exchange of data between the TDS experts and operating personnel was in the form of paper-based reports, certificates and memorandums (notes).

The next important stage was the integration of the LDS systems into packages of systems. This could be observed in the designs of Kalinin NPP’s units 3 and 4, and of Rostov NPP’s units 1 and 2. It was there that the concept of the monitoring, control and diagnosis system (MCDS) appeared. For correct operation of their algorithms, the systems in the MCDS received information from the upper unit level systems, while simultaneously sending its operation results to the power unit network. However, as earlier, the display of the MCDS operation results was predominantly neglected. Information was often incomplete and not entirely understandable to operating personnel. Further, as an example, we shall consider the format of the TDS information display at unit 4 of Kola NPP (Fig. 1).

And, finally, it is planned that stage 4 will be implemented in the VVER-1200 AES-2006 design for Novovoronezh II.

The authors have reviewed the strong and weak points in the diagnostic data supply to operating personnel. However, prior to proceeding to the results achieved, it is required to look at the problems concerned with the scope and nature of the needed TDS information to be transmitted to operating personnel.

Requirements to diagnostic data for upper level

We shall formulate the key requirements to the TDS information supplied to the upper unit level.

Intuitively understandable display of parameters

It so often happens that “intuitive understandability”, as it is seen by developers, is not treated in the same way by end users. A very graphic example for one to understand this problem may be the fact that, with the advent of digital technology, designers tried to convert any instrument reading to a digital format. But, as has been shown by practice, vital to the operator is not the parameter value accurate to two or three places of decimals (as an example) but the position of the needle on the scale which unambiguously showed to the normal or, on the contrary, to an abnormal status of equipment. The realization of this fact has brought needle indicators back both to the modern aircraft cabins and to the operator rooms where instantaneous perception of information is critical to decision-making. Naturally, the needle positions on the scales are simulated by computers, but this in no way makes the perception of information less valuable.

Absence of information capable to mislead the operator

The amount of information displayed in the screen is referred to as screen density. Studies have shown that the smaller is the screen density, the more accessible and user-understandable is information, and, vice versa, if the screen density is high, this may hamper comprehension and adequate interpretation of information. It is important to identify the smallest possible amount of readings capable to give the largest possible amount of information. No unnecessary or inaccurate information should be displayed because this may be harmful.

Naturally, all of the available information may be displayed. But the question is: what for? First, all the same, the operator will

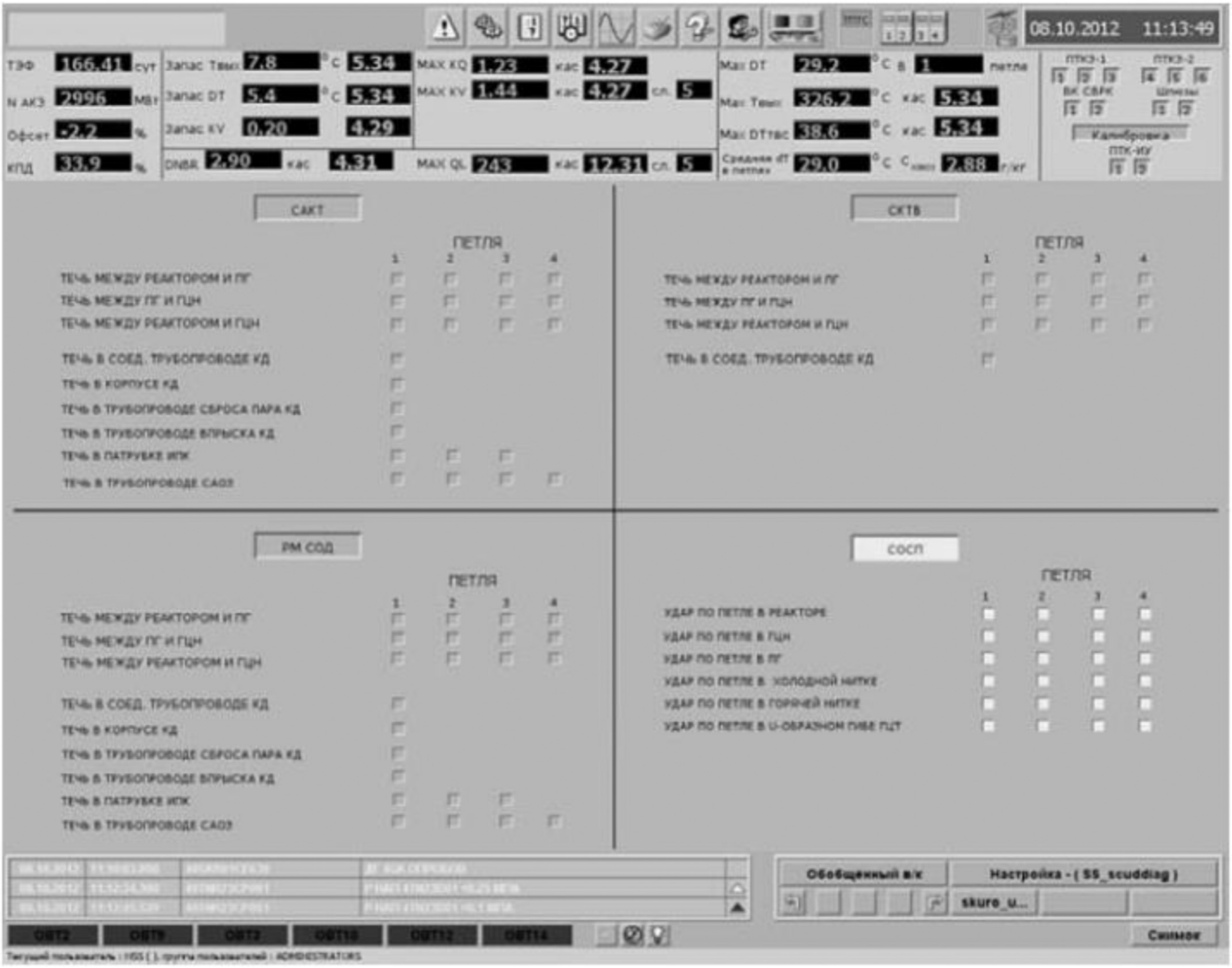


Fig. 1. A screen form for the diagnostic system data display at unit 4 of Kalinin NPP.

not have enough time to percept all information displayed, and there is an increased risk of missing something really important. Negative consequences are increased manifold in production environments with rapidly running transients if the response to an event or to the information about it is untimely. First, accurate instructions exist to regulate the operator actions, and any "information noise" may have a negative effect on the operator activities, especially in stress situations. In most cases, the very fact of a malfunction (a leak, a loose object in the circuit, increased vibration or else) is what is important.

Phased presentation of information

As shown above, display of data, both of any type and diagnostic, suggests a permanent balance between required and secondary information. It is not always possible to achieve an ideal proportion (a sort of a "golden section"). However, if the operator will be at once supplied not with the entire amount of information but with only data that is critical to the situation assessment, the perception and analysis of information will undoubtedly grow. An analogy with an ordinary magnifying glass will be not inappropriate here. People usually use a magnifying glass when they try to examine in detail something not visible to the naked eye, and this makes small items larger and more visible. It is the same way with diagnostic information: the operator is expected to see, by just even casting a glance at the screen, if all of the equipment is functioning normally, but, at the same time, a hierarchical function needs to be implemented for presentation of increasingly more detailed information so that much information could be obtained on any event.

Conformity to the interface organization standards accepted at NPPs

This requirement is standard and, as authors see it, as understandable as it can be. Operation in a single information environment requires diagnostic information to conform in full to the standards specified by the design. We shall note that it is exactly the data display techniques (color coding, line thickness, schematic representation of equipment and so on) what is meant here rather than what is to be displayed in the screen.

New approach to hierarchical presentation of diagnostic data

For graphically comparing the new approach to the diagnostic data display and what has been done to date, we shall analyze the screen forms used for presentation of diagnostic data at VVER-1200 units in the design of Kalinin NPP's unit 4 (Fig. 1).

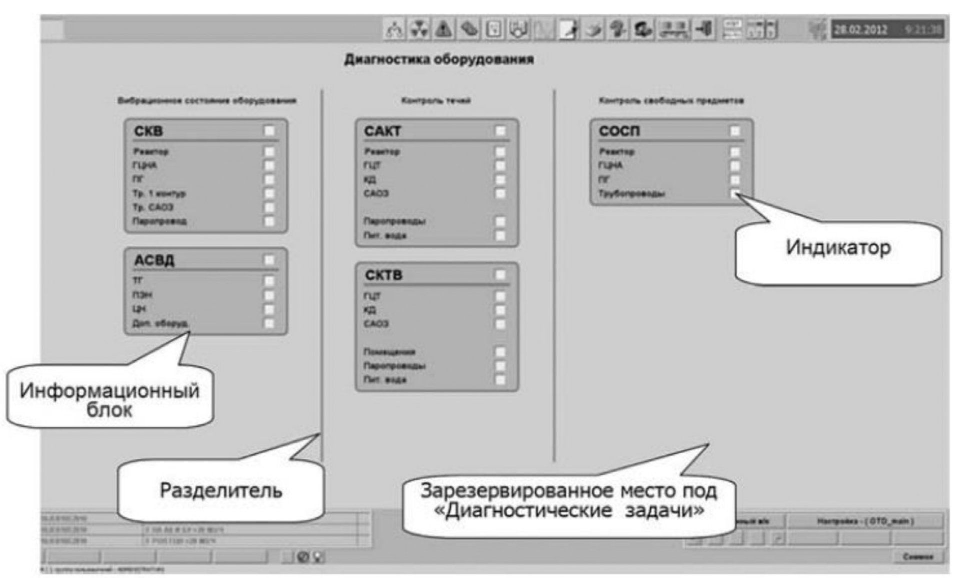
As a positive practice, it should be noted that the given screen form satisfies in full to the design requirements for the presentation of data in monitor screens, that is, the colors of information items, the line thicknesses and the fonts are similar to those available in other screen forms which display the status of other systems, that is, the interface is conventional for operating personnel and causes no difficulties.

Besides, information on the detected abnormal events is supplied to the operator explicitly. A color change signals that an abnormal event is detected (green indicates that there are no anomalies, and red indicates that a shock event is detected). Apart from the event recording as such, information on the recording point is available. The presentation of components is conventional, but, in a first approximation, it is enough for decision-making and for taking corrective actions. However, in the authors' opinion, the data presentation algorithm has been developed not as thoroughly as it should be. Thus, for example, it is not possible to switch over from the displayed screen form to a form containing more detailed data on the detected event, that is, no principle of phased data presentation has been observed.

Another major drawback is that the set of diagnostic information is not complete. Unit 4 of Kalinin NPP includes an MCDS having as a minimum (apart from acoustic and humidity leak detection systems and a loose object detection system) a vibration monitoring system. Tracking of vibration levels as such is an important diagnostic symptom of the equipment "serviceability status", leave alone the fact that there are distinct vibration boundaries (defined in managing documents) which allow classifying components unambiguously as "serviceable" or "not serviceable". So the question of no equipment vibration levels being shown in the given screen form is appropriate. In the authors' opinion, the problem of displaying the equipment vibration status has not been resolved due to a high density of the diagnostic data displayed. With something else added to the existing data, information stops to be perceivable.

We shall consider another approach to be implemented in the AES-2006 design at Novovoronezh II. Fig. 2 presents the start screen form available to the NPP's operating personnel. It will display data on the status of components and it will be also possible to switch over from this form to other screen forms for more detailed examination of abnormal events and for understanding how dangerous they are.

As can be seen from the figure, the start screen form displays the minimum data set for perception (including information on the vibration status of the primary and secondary circuit components). It should be noted that it displays much less diagnostic data elements than the screen form at unit 4 of Kalinin NPP, which, ultimately, reduces the information load on operating personnel. The TDS information is grouped into data units depending on the system functions performed, including "Equipment Vibration Status", "Leak Monitoring" and "Loose Object Monitoring". The units are signed and separated from each other



Информационный блок = Data unit
Индикатор = Indicator
Разделитель = Splitter
Зарезервированное место… = Screen place for "Diagnostic Tasks"

Fig. 2. A screen form for the diagnostic system data presentation for unit 1 and 2 of Novovoronezh II (design).

by vertical lines (splitters). A major advantage offered by such approach is that operating personnel understand at a glance to which class of events the anomaly belongs (increased vibration, a leak or a loose object) when an abnormal event takes place (e.g., the indicator changes from green to red). Therefore, the required amount of information for corrective actions to be taken is available to operating personnel at the very first moment. To obtain more detailed data, it is possible to unfold screen forms sequentially with growingly more detailed displayed at each step, and the authors think it necessary to limit the unfolding depth to one or two steps.

As an example, we shall consider the data receiving algorithm for a case of the abnormal event detection in the state of the main circulation pumps (MCP). A dedicated system is used for the MCP technical diagnosis. The system measures vibration in all channels, compares the vibration levels against the selected threshold values and, using the preset algorithms, supplies complete diagnostic messages to operating personnel. An abnormal event is recorded as follows. The two indicators in the start screen form (see Fig. 2) will change from green to red: the first one opposite the name of the system that has recorded the event (VMS), and the other opposite the designation of the component, i.e. the MCP. Therefore, operating personnel receive important information – a MCP anomaly (the event has been recorded by was VMS system) – at the initial step. More detailed information can be received by switching over to the next screen form (it is suggested that the switchover will be through pushing the button on the computer manipulator of the mouse or trackball type) (see Fig. 3).

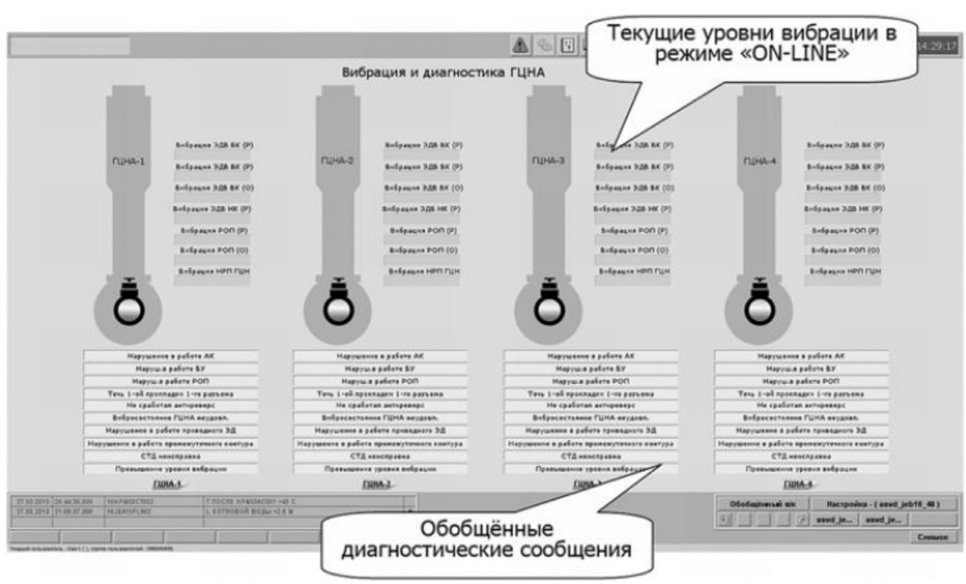
If only the most common factors of the abnormal situation are identified based on the results of analyzing the data in the initial screen form, that is, the class of the abnormal situation (one of three) and the class of the components (MCPs in the above example), the second screen form enables the particular MCP to be identified, and it is also possible to track the current vibration levels online. Besides, this screen form displays generalized diagnostic messages which help operating personnel identify, in a first approximation, the cause for the component's abnormal state.

If it is necessary to examine in detail the state of the particular MCP, it is possible to switch over to the screen form of level 3 containing the most detailed and extended information on the state of the selected MCP (Fig. 4).

This form displays all abnormal situations defined by the technical specifications for the MCP diagnosis system (these are grouped into data units depending on similar symptoms). Therefore, it is in this screen form that the end cause (in the form of a complete diagnostic message) will be identified. Summing up in brief the phased data presentation process, it is easy to see how the amount of data is increased at each step and the item diagnosed is identified. The future will show to what extent this approach is justified or if it will be welcomed by operating personnel.

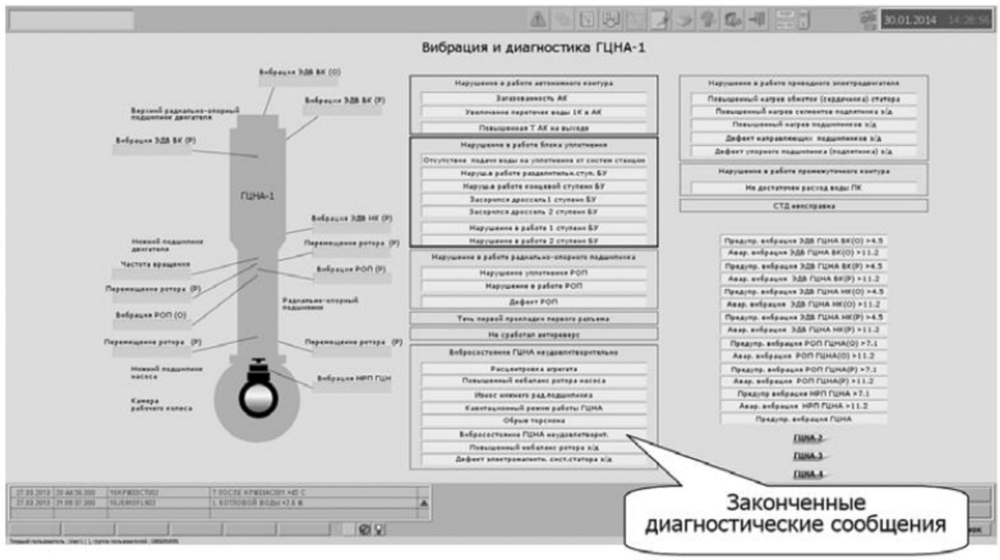
Going back to Fig. 1, one more novelty introduced by the authors shall be noted, namely “Diagnostic Tasks”. In the course of operation, all TDS systems process a great deal of incoming data which ultimately forms an array of diverse information. “Diversity” means that one portion of information does not require operating personnel to have a special background or any special knowledge. Primarily, this is the case when the measured signal exceeds any preselected values (settings).

Exactly such parameters are displayed in the start screen form. As the result of the TDS operation, the output data array may also contain spectral estimations of signals, different



Текущие уровни… = ON-LINE current vibration levels
Обобщенные диагностические сообщения = Generalized diagnostic messages

Fig. 3. Level 2 screen form for the MCP state diagnosis.



Законченные диагностические сообщения = Complete diagnostic messages

Fig. 4. A screen form for the diagnostic data presentation at unit 4 of Kalinin NPP.

correlation functions and many more, which is absolutely incomprehensible to and in most cases not needed by operating personnel. These are a sort of two poles in presentation of diagnostic information. A question arises if there is anything average in the output data array which, while being not very difficult to understand a physical sense, is at the same time easily formalized. It does, the authors believe! Thus, for example, a pattern can be obtained as the result of the VMS operation for major process equipment displacement due to thermal expansion. Do operating personnel need this information? Not always but they do! So this task will be solved in the start format. As agreed with the designers, the list of such tasks will be further developed and presented in the start screen form. They are no yet shown in the figure because of the complete list being currently at the stage of approval.

By now, it seems reasonable to limit the diagnostic tasks to the following:

- displacement of the main components due to thermal expansion;
- diagnosis of internals for vibration noise;
- diagnosis of electrically operated valves;
- monitoring of the equipment fatigue status.

Conclusion

The paper considers the key issues concerning the presentation of data from technical diagnosis systems, as well as the major problems involved in the perception of such information by the NPP operating personnel. Key requirements to presentation of data at different hierarchical levels have been formulated. Screen forms are presented as developed by the authors for the VVER-1200 unit of Novovoronezh NPP.

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